ANALOG SITE FOR CHARACTERIZATION OF FLOW AND CONTAMINANT TRANSPORT IN FRACTURED ROCK

TECHNOLOGY NEED

A number of contaminated DOE sites are above fractured rock. These sites include the Idaho National Engineering and Environmental Laboratory (INEEL), the Oak Ridge Reservation, and Los Alamos National Laboratory (LANL). At such sites, finding an appropriate conceptual model of water and relative chemical transport in fractured rocks is a key issue faced by remediation managers. Use of an incorrect conceptual model is responsible for many significant errors in making predictions and worse than expected remediation results. To develop a useful model, a basic understanding of the physical processes is required, and that can be obtained by monitoring ambient conditions, controlled tests, or remediation activities. Such monitoring is not straightforward in fractured media, however, because flow and transport are largely controlled by heterogeneous parameters. Without an understanding of where flow is likely to go, monitoring instruments cannot be deployed effectively. Therefore, there is a need to concurrently improve the conceptual understanding of flow and transport in fractured rocks and the means for monitoring these processes.

This work addresses INEEL Site Technology Coordination Group (STCG) Need Numbers:

- 6.1.13 *In Situ* Bioremediation of Trichloroethylene (TCE) Contaminated Groundwater in Fractured Rock at 200- to 400-Foot Depths
- 6.1.16 *In Situ* Treatment of TCE Contaminated Groundwater in Fractured Rock at 200- to 600-Foot Depths
- 6.1.22 *In Situ* Immobilization of Radionuclides (Cesium, Strontium, Uranium, and Technetium) Contaminants in Groundwater in Fractured Bedrock at 100- to 600-Foot Depths
- 6.1.23 Improved Methods to Pump Perched Water (in Fractured Basalt) from beneath the Idaho Chemical Processing Plant (ICPP)
- 6.1.28 Develop a Means for Making Organic Contaminants in the (Fractured) Vadose Zone More Available to Increase the Efficiency of Valpor Vacuum Extraction Operations. (Currently limitations exist due to diffusion rate constraints.)

This work addresses Oak Ridge STCG Need Numbers:

- HY-01 DNAPL Source Characterization and Delineation: Delineation is difficult for less permeable lenses or in bedrock fractures, but necessary to provide cost-effective remediation technologies to reduce or eliminate these persistent sources of contaminant release to groundwater.
- HY-06 Fractured Media Flow Characterization: Contaminant migration at some of the Oak Ridge facilities is controlled by fractures, joints, and bedding planes. Technology advancement is necessary to better characterize and predict how contaminants will be transported through fractured formations on a local as well as large scale in order to assess potential remediation and design exit-pathway monitoring systems.
- HY-07 Deep DNAPL Source Containment: To contain these source areas from migration or continuing long-term dissolution to the groundwater will require overcoming severe depth or resistant subsurface constraints. At Oak Ridge sites, DNAPL may have penetrated several hundred feet into fractured media, making containment extremely difficult.

The conventional approach is to apply porous medium methods. However, those methods are designed for homogeneous systems and, therefore, are poorly suited to strongly heterogeneous and fractured systems. When remediation methods fail because they are applied without understanding the hydrologic behavior of a complex fractured system, it is often claimed that the remediation methods themselves do not work rather than admitting that the methods are being incorrectly applied.

TECHNOLOGY DESCRIPTION

This project features concurrent development of a conceptual model and field monitoring tools and methods to monitor and control flow and transport in fractured rocks. This project has deployed several geophysical instruments and moisture measuring devices to characterize groundwater flow through fractured basalt at the INEEL.

BENEFITS

Improved monitoring and controlling tools, methods, and a conceptual model will improve decisions and reduce costs in regards to the following issues: where to take samples and emplace sensors; where to drill and pump; and where and how to emplace barriers. There can be enormous cost savings if natural attenuation can be established as an acceptable alternative to removal. Successful characterization may lead to the decision to contain rather than remove contamination, again with enormous potential cost savings.

CAPABILITIES/LIMITATIONS

The basic premise of this effort is to support the design of appropriate remediation activities based on an understanding of the complex, fractured rock system rather than blindly applying techniques developed for more homogeneous, unfractured porous media. Because strongly heterogeneous fractured systems themselves are more complicated, flow and transport through them are more complicated, and therefore effective remediation is likely to be more complicated as well. If site operators performing remediation restrict themselves to applying simple solutions to complicated problems, they are likely to be disappointed with the results.

COLLABORATION/TECHNOLOGY TRANSFER

Active partners in this work have included INEEL for instrument development and deployment, field testing, and data analysis; Stanford University for geomechanical modeling of basalt flows and field fracture mapping; and ESEA, Inc. for scientific visualization coupled to a graphical database. Government funding on closely related projects has come from DoD and other programs within DOE. Private companies providing services related to the work include Core USA, Inc. for the borehole scanner and SteamTech, Inc. for the three-dimensional (3-D) Electrical Resistivity Tomography.

A patent is pending for a water pressure-measuring device developed by the CMST-CP, and use-licenses have been issued for an advanced tensiometer and a portable tensiometer.

ACCOMPLISHMENTS

Technologies developed and applied for single-borehole geologic characterization and monitoring of flow and transport in fractured rock include the following:

- Slanted wells were used to intersect vertical fractures.
- Video and borehole scanning.
- New borehole completion design using polyurethane foam.
- A combination of point measurements including tensiometers, suction lysimeters, time-domain reflectometry, thermistors, and miniature electrical resistivity probes.
- Cross-hole techniques including ground penetrating radar, seismic (in particular guided wave studies), electrical resistivity tomography, and air interference tests.

The field tests conducted included ponded infiltration tests, gas-phase flow tests, and transport (heat, tracer) tests.

The conceptual and mathematical models developed include:

- Geomechanical modeling of basalt flow cooling that yields predictive capability for fracture patterns.
- A conceptual model of flow and transport based on the hydrogeologic components of a fractured basalt vadose zone at the scale of tens of meters.
- Feature-based mathematical modeling of hot air injection test and ponded infiltration tests.
- An Inverse analysis of a saturated-zone interference well test.

A general description of the Fracture Analog project, including site characterization, hydrologic, and geophysical data from infiltration and tracer tests at Box Canyon, near the INEEL, is available at http://www-esd.lbl.gov/ERT/inel/inel.html. The data provide a comprehensive picture of liquid infiltration in a fractured medium, using TDR, tensiometry, electrical resistivity probes, water and tracer sampling, and cross-borehole radar. Such data supports characterization, monitoring, and remediation activities in fractured rock vadose zones. A complete set of reports and journal articles prepared during the course of the project or currently in preparation is also included there.

TECHNICAL TASK PLAN (TTP) INFORMATION

TTP No./Title: SF14C221 - Analog Site for Characterization of Fractured Rock

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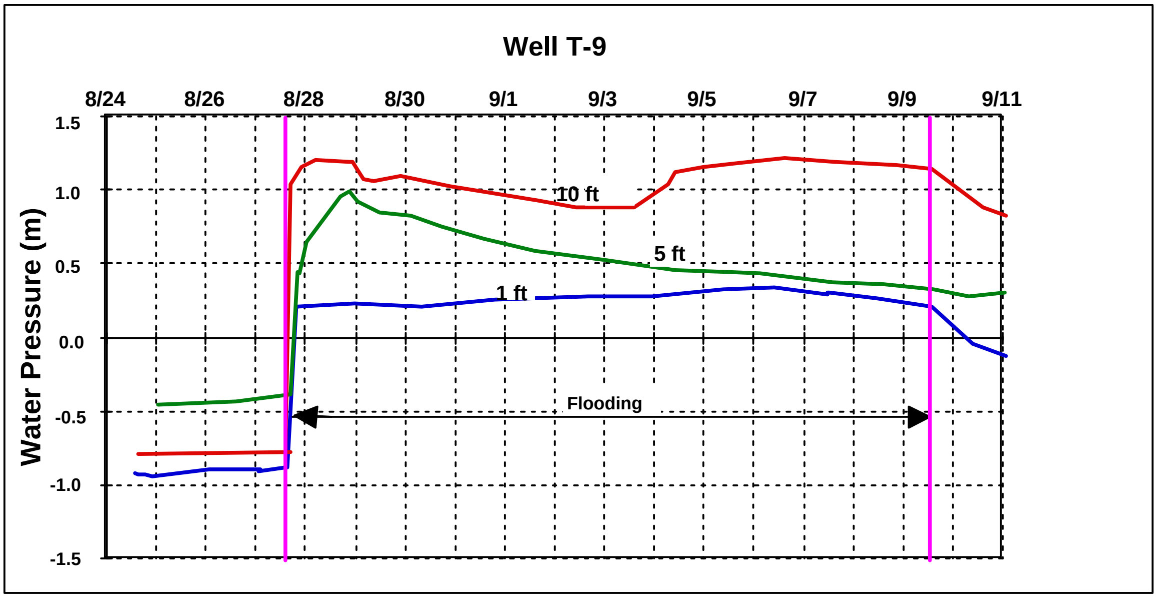

Water pressure changes in fractured basalt in Analog Well T-9 are being monitored to develop methods to monitor and control contaminant transport in fractured rock.